INEEL/EXT-02-01306
Revision 0

Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999–2002

Nicholas E. Josten

December 2002

Idaho National Engineering and Environmental Laboratory
Bechtel BWXT Idaho, LLC

INEEL/EXT-02-01306
Revision 0

Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999–2002

Nicholas E. Josten

December 2002

GeoSense
Idaho Falls, Idaho 83404

Prepared under Subcontract No. 00003717
for the U.S. Department of Energy
Assistant Secretary for Environmental Management
Under DOE Idaho Operations Office
Contract DE-AC07-99ID13727

Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999–2002

INEEL/EXT-02-01306

December 2002

Approved by

T. J. Meyer

12-19-02

T. J. Meyer, Bechtel BWXT Idaho, LLC
WAG 7 Project Engineer

Date

ABSTRACT

This report is a compilation of a large number of informal analysis efforts that have been conducted since 1999 in support of WAG 7 and Environmental Restoration at the Idaho National Engineering and Environmental Laboratory Subsurface Disposal Area. Much of the material collected here has not been published in any form, although it has been used to support ongoing environmental restoration decision-making for several years. The primary purpose of this report is to provide this information in a document that can be referenced. The document contains information on geophysical logging, nuclear logging, and the interpretations and analyses that have been performed based on these logging activities. The report also contains visual images recorded within the visual probes with an optical televiewer. The information has been included in the document in its original form, and interpretations have not been revised so that they remain consistent with original analyses.

This page is intentionally left blank.

CONTENTS

FIGURES

TABLES

This page is intentionally left blank.

ACRONYMS

CT	carbon tetrachloride
DU	depleted uranium
EM	electromagnetic
INEEL	Idaho National Engineering and Environmental Laboratory
OU	operable unit
RFP	Rocky Flats Plant
SDA	Subsurface Disposal Area
SVR	soil vault row
VOC	volatile organic compound

This page is intentionally left blank.

Compilation of Analytical Notes and Data Analyses for the Integrated Probing Project 1999–2002

1. INTRODUCTION

This report is a compilation of a large number of informal analysis efforts that have been conducted since 1999 in support of Environmental Restoration at the Idaho National Engineering and Environmental Laboratory's (INEEL's) Subsurface Disposal Area (SDA). Much of the material collected here has not been published in any form, although it has been used to support ongoing environmental restoration decision-making for several years. The primary purpose of this report is to provide this information in a form that can be easily referenced.

Because the information has been recovered from a wide assortment of informal sources and because the nomenclature pertaining to project and place names has changed, there is some inconsistency in naming conventions. For instance, using existing figures helped to avoid the costly effort of regenerating graphics.

Some of the analysis results contained in this report represent interim data compilations and/or conclusions.

2. BACKGROUND

2.1 Description of Geophysical Investigations

Two types of geophysical data were used for the analyses presented in this report. The first was surface geophysical data collected over many years of SDA operations. These data were used mainly to delineate waste versus nonwaste areas, a basic segregation that supports many of the analyses presented in this report. The second was downhole geophysical logging data, which provides information on in situ conditions within the waste zone, overburden, and underburden.

2.1.1 Surface Geophysics

Table 2-1 lists 10 surface geophysical studies that have been conducted at the SDA since 1989. These studies were conducted either to meet specific Environmental Restoration needs or as part of technology development and demonstration projects. The geophysical surveys range in scale from single pit surveys to surveys of the full SDA. In some cases, digital data have been preserved for some of these surveys and may be obtained from INEEL archives. In other cases, report tables and graphics provide the only record of the field measurements.

Most surface geophysical surveys at the SDA were conducted to delineate waste. Surface geophysics data have helped resolve several important discrepancies concerning SDA pit and trench boundaries (Josten and Thomas 2000).[a] Magnetic and electromagnetic geophysical methods are ideally suited for this application because they have excellent sensitivity to metallic waste such as drums, which make up a large proportion of SDA waste. Surface geophysics data are routinely consulted prior to drilling or excavating within the SDA to minimize the potential for disturbing hazardous materials in the subsurface. Surface geophysics surveys have also been used to estimate depths to the top of waste and to bedrock beneath the waste, which are parameters that are useful for estimating waste and soil volumes as part of remedial planning. Overall, the geophysical data have provided a useful basis for general planning and safety purposes for many years to come.

2.1.2 Downhole Geophysical Logging

From 1999 to 2001, 139 Type A steel probes were installed into Pits 4, 5, 9, and 10. The probe locations were chosen based on combined analyses of surface geophysics and waste inventory records. A suite of geophysical logging tools was deployed in these probes to investigate subsurface characteristics of buried waste. Table 2-2 lists the geophysical tools used and gives a brief summary of the scope of the SDA logging program.

The geophysical logging data have yielded a wealth of qualitative and semiquantitative information concerning the distribution of radionuclides and chlorinated solvents in the subsurface. The logging tools have only a limited depth of investigation (~0.5–1.0 ft), but the probe hole arrays offer a basis from interpolating the distribution of contaminants over large areas. Quantitative analysis of these data will be used to improve contaminant source-term estimates and contaminant mobility parameters, which in turn will support improved risk assessment. Table 2-3 gives a summary of contaminant detection for the overall SDA logging program.

---

[a] Carpenter, G. S., 1992, "Interpretation of SDA TRU Pits and Trenches Geophysical Survey," Interoffice correspondence from G. S. Carpenter to C. M. Hiaring, September 30, 1992, Idaho National Engineering and Environmental Laboratory, Idaho Falls, Idaho.

Table 2-1. Summary of Subsurface Disposal Area surface geophysical surveys from 1989 to 2001.

Performer	Date	Methods	Survey Area	Digital
UNC Geotech[a]	1989	Magnetics, electromagnetics (EM), seismic	Pit 9, Acid Pit	No
Buried Waste Robotics[b]	1991	EM	Pit 9	No
Ebasco Environmental[c]	1992–93	Magnetics, EM	Entire Subsurface Disposal Area	Yes
EG&G Idaho[d]	1992	Magnetics	Pit 9	Yes
S. M. Stoller Corporation[e]	1995	Magnetics, EM, seismic	Pit 9	No
GeoSense[f]	1998	Magnetics, EM	Pit 9	Yes
United States Geological Survey[g]	1999	EM	Pit 9	No
Harding Lawson Associates[h]	1999	Magnetics, EM, seismic	Pits 4, 6, and 10	Yes
Sage Earth Science[i]	1999	Magnetics, EM	Pits 2, 3, and 5; Soil Vault Rows 1–12, 14	Yes
Sage Earth Science[j]	2001	Magnetics, EM	Soil Vault Row-20	Yes

a. Hasbrouck 1989
b. Griebenow 1992
c. Ebasco Environmental 1993
d. Roybal, Carpenter, and Josten 1992
e. Stoller 1995
f. GeoSense 1999
g. Wright, Smith, and Abraham 1999
h. Appendix A
i. Sage 1999
j. Sage Earth Science, 2001, Informal submittal to BBWI engineer J. Casper, Idaho Falls, ID.

Table 2-2. Summary of Subsurface Disposal Area geophysical logging program.

Tool	Primary application	Number Probes Logged	Linear Feet Logged
Passive spectral gamma ray	Detect gamma-emitting radionuclides	136	2,159
Passive neutron	Detect neutron-emitting transuranic radionuclides	136	2,280
Neutron-activated spectral gamma ray	Detect chlorine	139	2,093
Neutron-neutron moisture	Measure moisture content	139	2,203
Azimuthal spectral gamma ray	Delineate compact versus distributed radioactive sources	30	46[a]

a. Azimuthal surveys conducted at 46 discrete depths.

Table 2-3. Overall summary of downhole logging results.

Parameter	$^{239}Pu\_414$	$^{241}Am\_662$	^{237}Np	$^{235}U\_186$	$^{238}U\_1001$	^{137}Cs	Chlorine
Units	nCi/g	nCi/g	pCi/g	pCi/g	pCi/g	pCi/g	counts/second
RCB	28.76	36.6	48.99		37.79	183.29	NA
Background	0.1	0.014	NA	NA	1.4	0.82	NA
Total measurements	4,863	4,863	4,863	4,863	4,863	4,863	4,540
Number of detects	1,261	1,068	511	261	862	367	1,936
Number of nondetects	3,602	3,792	4,352	4,602	4,001	4,496	2,604
Minimum concentration	7.2	7.7	0.1	0.5	7.2	0.05	0.2
Maximum concentration	194,171.0	30,449.0	4,881.0	344.9	220,894.0	140.5	38
Average concentration	2,245.6	838.4	48.0	21.6	2,299.5	5.2	7.4
Number above RCB	1,261	1,068	79	25	640	0	NA
Number above background	1,261	1,068	NA	NA	862	146	NA
detect%	26%	22%	11%	5%	18%	8%	43%
nondetect%	74%	78%	89%	95%	82%	92%	57%

RCB = radiological control background

3. ANALYSIS RESULTS BY FOCUS AREA

The SDA logging program is part of an overall plan to evaluate the long-term health and safety risks associated with SDA buried waste. The logging program was subdivided into focus areas (Figure 3-1). Each focus area was selected to address a specific data need.

3.1 743 Sludge Focus Area

A volatile organic compound (VOC) transect survey across the eastern end of Pit 4 was designed to address uncertainty regarding the amount of residual volatile organic carbon compounds (VOCs) in SDA pits remaining from Rocky Flats organic sludges. Soil gas surveys conducted in 1987, 1988, and 1992 give a partial answer to this question since areas of elevated VOC soil gas could be identified; however, the soil gas surveys do not provide VOC mass information, which is needed to assess long-term health and safety risk.

Neutron-activated spectral gamma-ray (n-gamma) logging surveys provide a method to directly detect chlorine in the waste layer and to estimate VOC mass within the vicinity of a logging probe. Chlorine logging data may be compared with soil gas survey results. If the logging data are found to correlate spatially with soil gas survey results, the project proposes to pursue quantitative analysis of the chlorine logging data aimed at estimating the residual VOC source mass.

3.1.1 Selection of Probe Locations

Figure 3-2, which shows results from a 1998 soil gas survey of Pits 4, 6, and 10 indicates elevated VOC levels in the northeast corner of Pit 4. Inventory records show that this portion of Pit 4 received a high concentration of Rocky Flats 743-series sludge drums (see Figures 3-2 and 3-3). Since 743 sludge is known to contain chlorinated solvents including carbon tetrachloride (CCl_4), is a contaminant of concern, and is a primary risk driver in evaluation of SDA remedial options, this general location was selected for subsurface investigation by probing.

Surface geophysical data were plotted and compared with inventory information for the northeast corner of Pit 4 (Figure 3-3). Geophysics data showed a clear demarcation between the northern and southern portions of Pit 4, corresponding approximately with the limit of 743-series sludge drum disposals. A probe transect was designed to investigate this feature from the expected low (or background) VOC region on the south to the expected high VOC region in the north. The final transect location was chosen to accommodate exploration of the far northeast corner of Pit 4, where pilot scale feasibility studies were planned. The final probe locations are shown in Figure 3-4.

3.1.2 Qualitative Chlorine Mass Analysis

Figures 3-5–3-8 show a compilation of downhole logging data along the 743 Study Area transect. The following observations are based on these figures:

- Chlorine is concentrated in the central and northern portions of the transect, generally correlating with the CCl_4 soil gas profile, except that the logging data do not portray a large local chlorine mass increase on the north end.

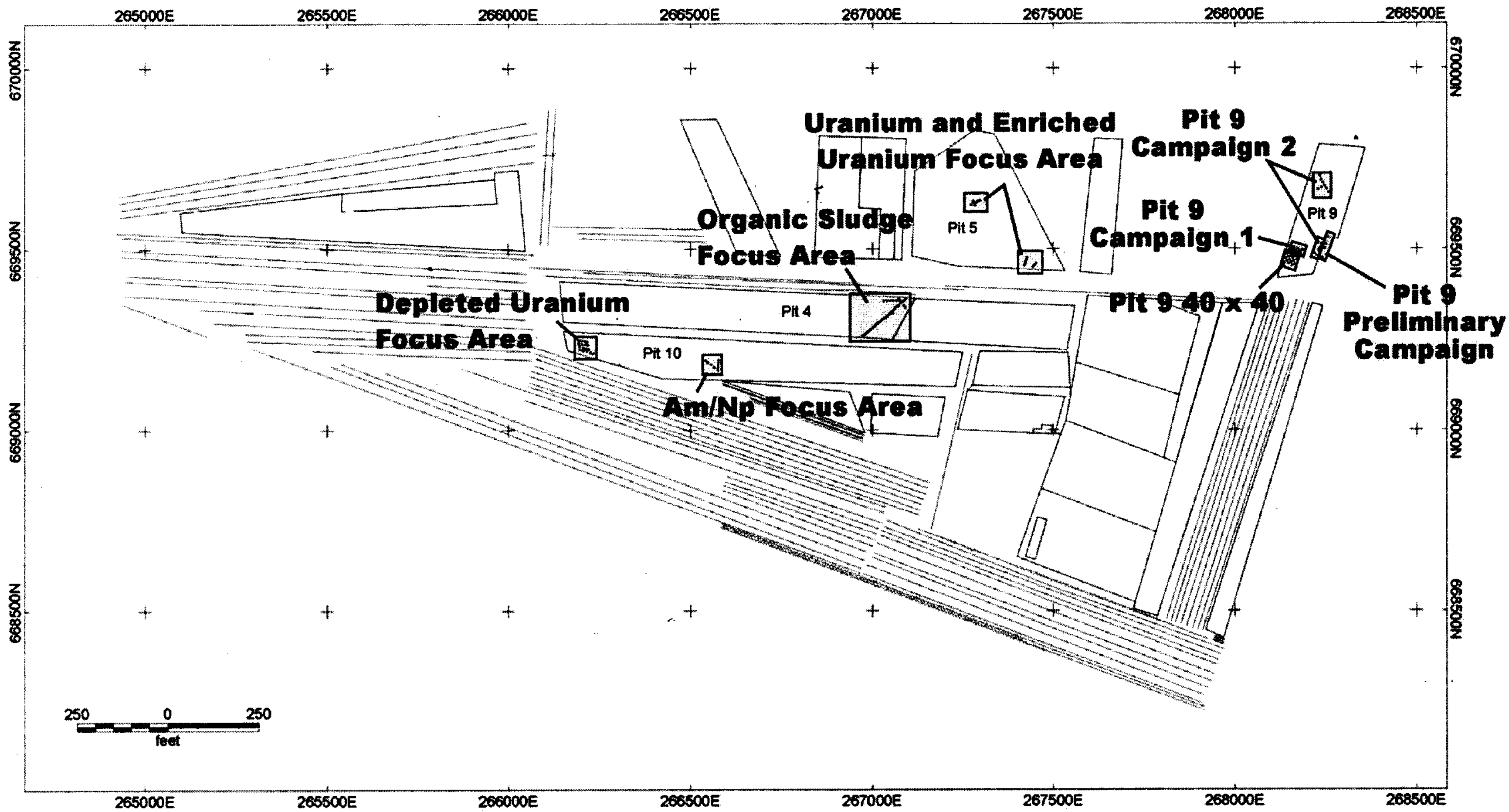

Figure 3-1. Subsurface Disposal Area probing campaign map.

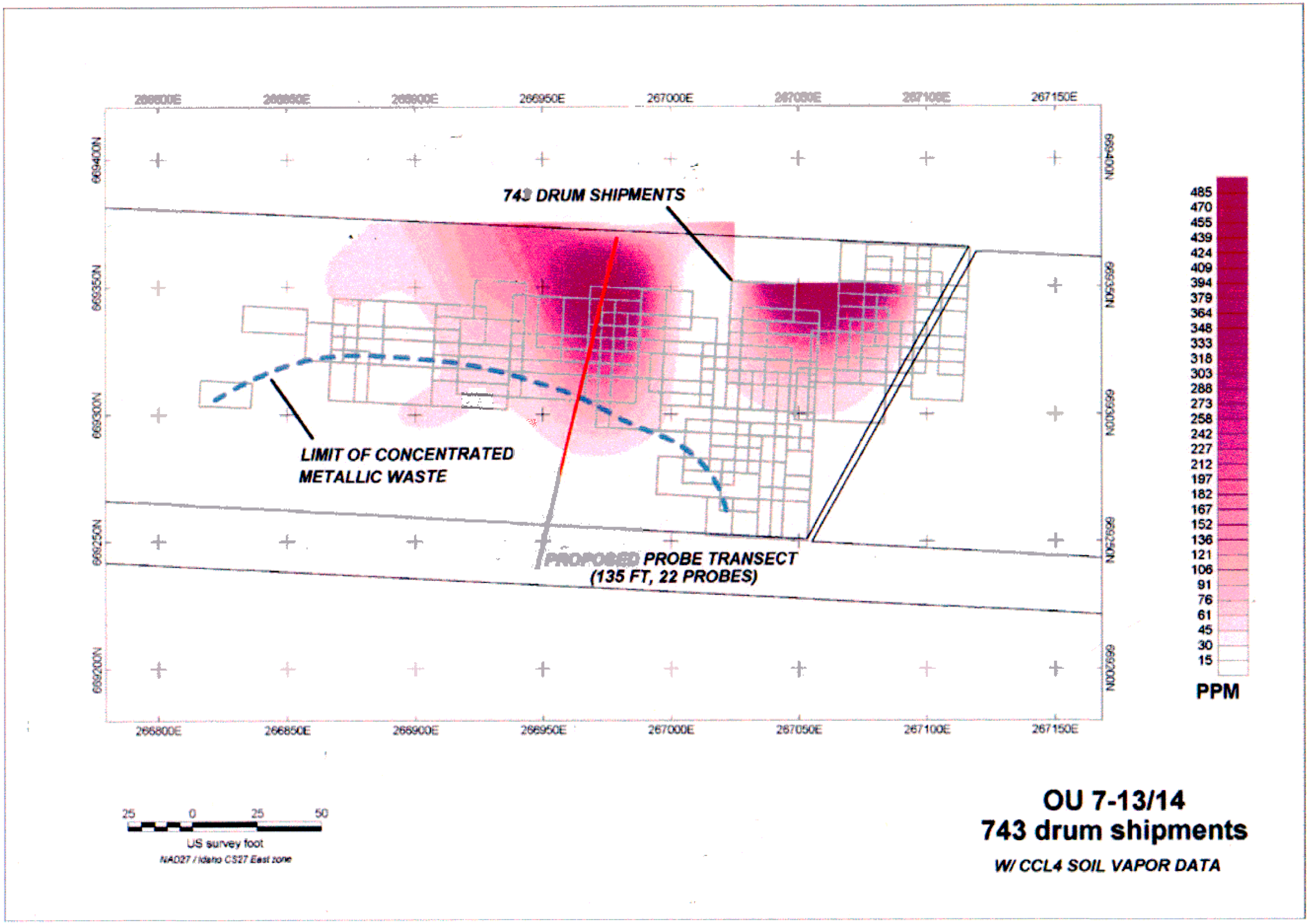

Figure 3-2. Soil gas survey data showing volatile organic compound gas plume over eastern end of Pit 4.

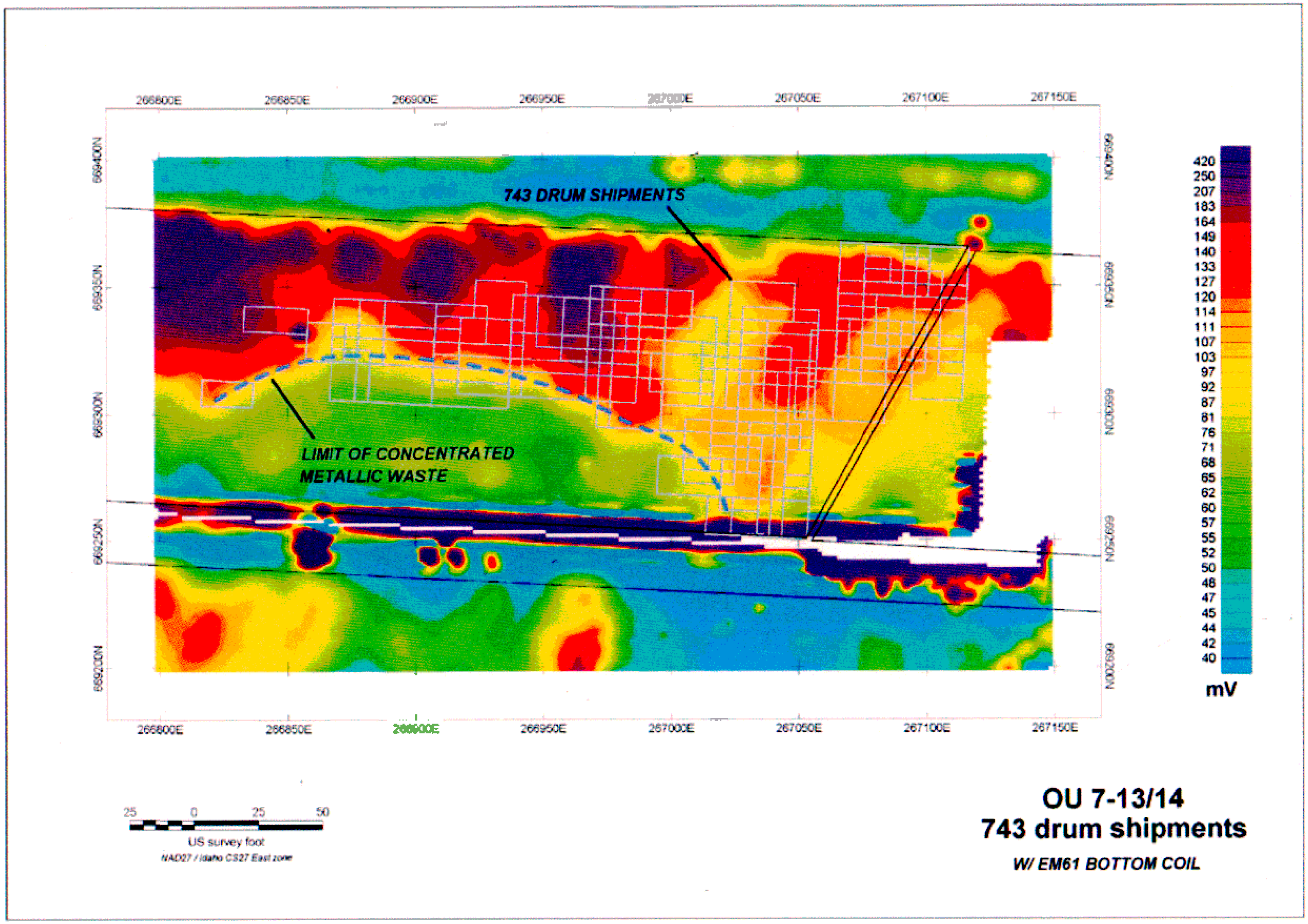

Figure 3-3. Map showing surface geophysics and waste inventory evidence for presence of Rocky Flats Plant 743-series waste at the eastern edge of Pit 4.

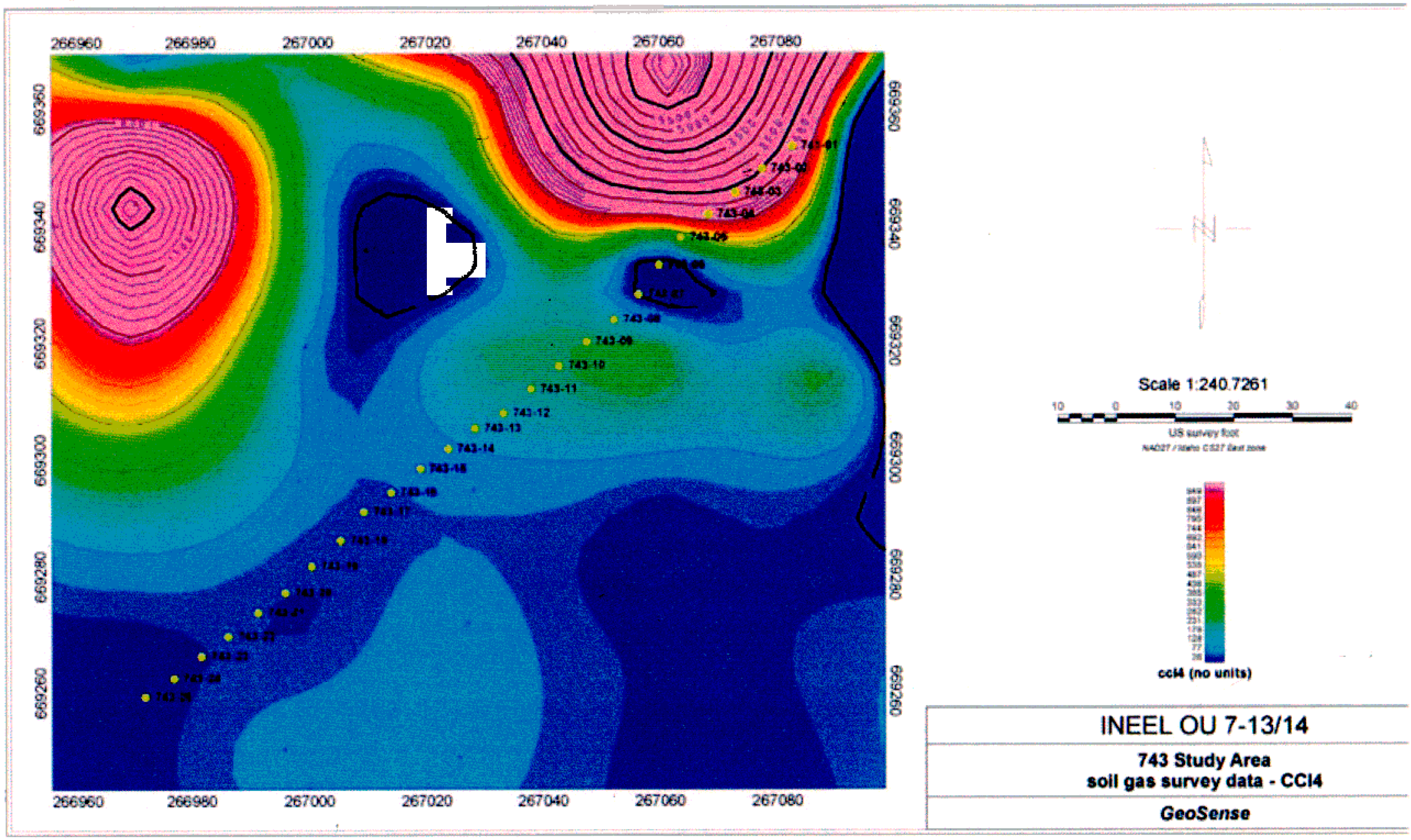

Figure 3-4. Map of 743 Study Area showing 1988 carbon tetrachloride soil gas data.

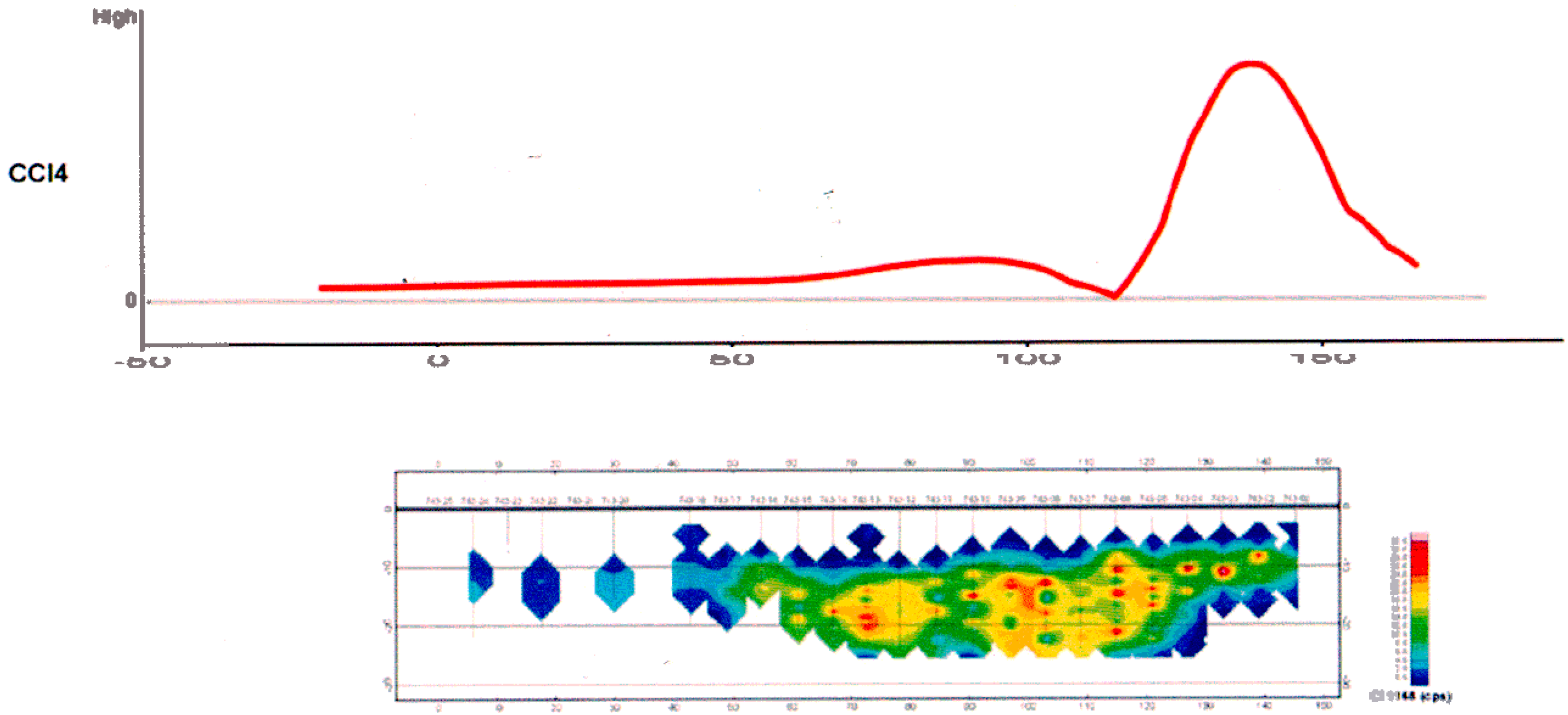

Figure 3-5. Cross section across 743 Study Area map showing 1988 carbon tetrachloride soil gas data.

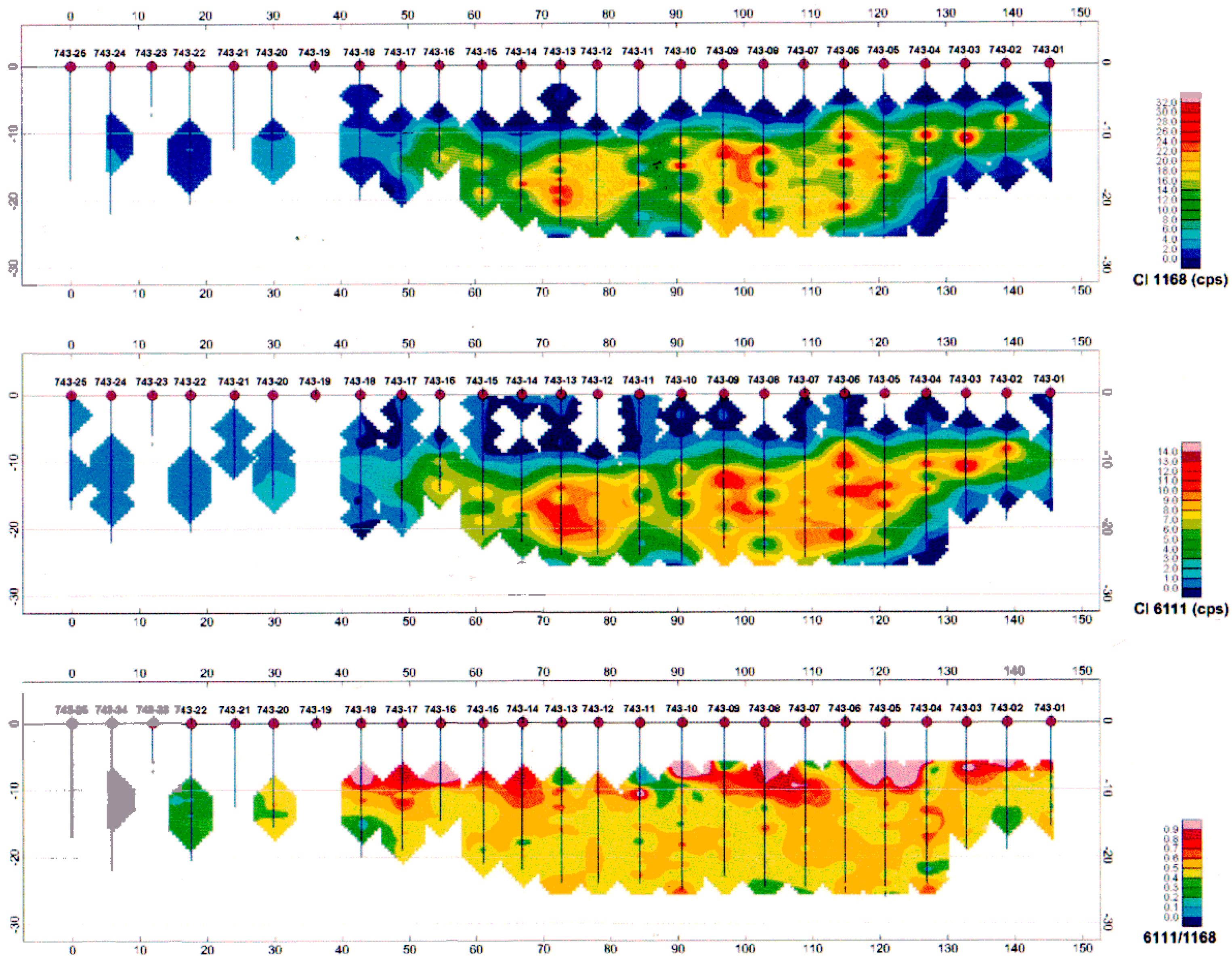

Figure 3-6. Summary of chlorine logging data: 1,168 keV (top), 6,111 keV (middle), and 6,111:1,168 ratio (bottom). Note linear color scales.

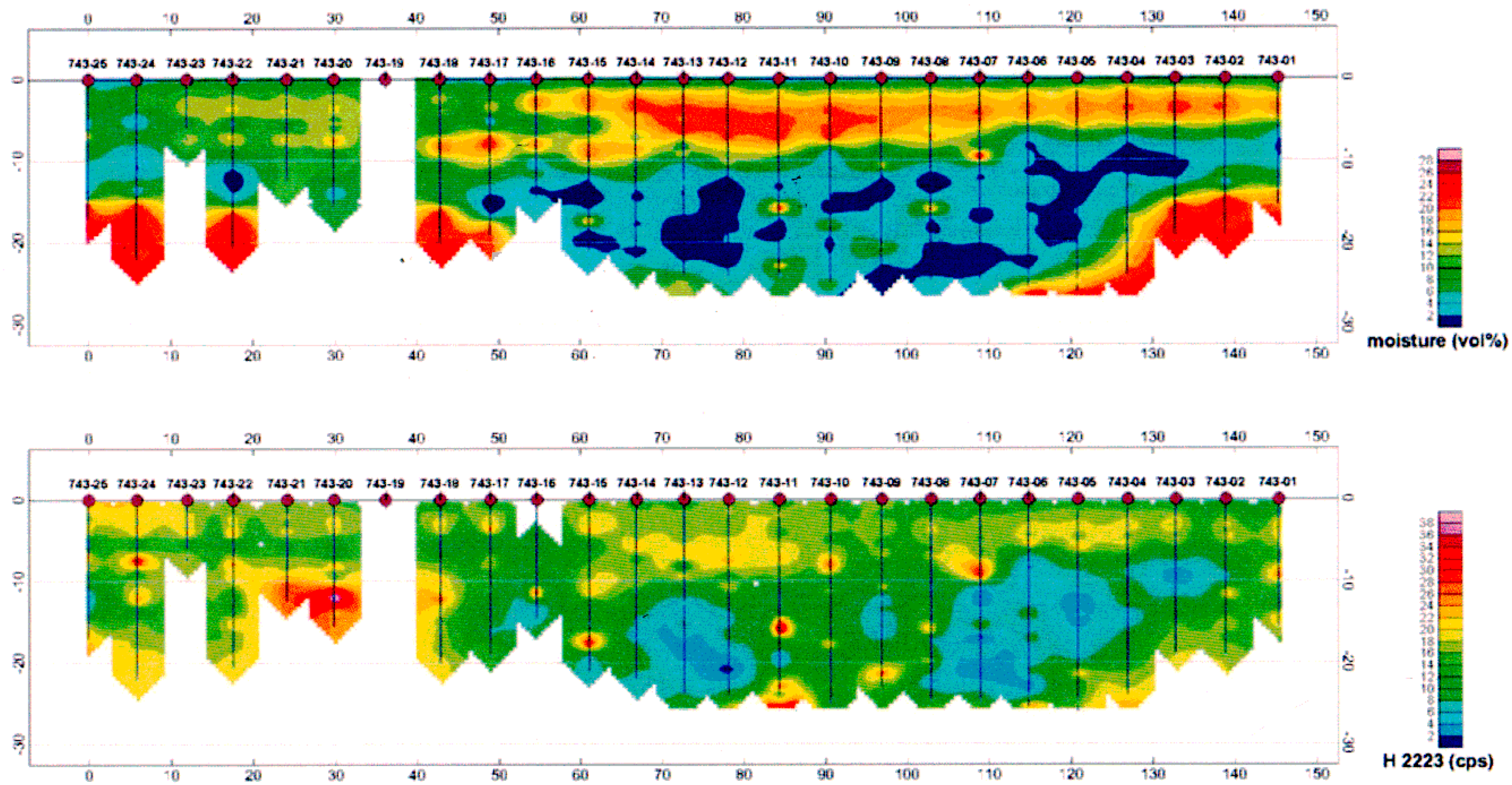

Figure 3-7. Moisture log (top) and n-gamma hydrogen_2,233 keV (bottom). Note linear color scale.

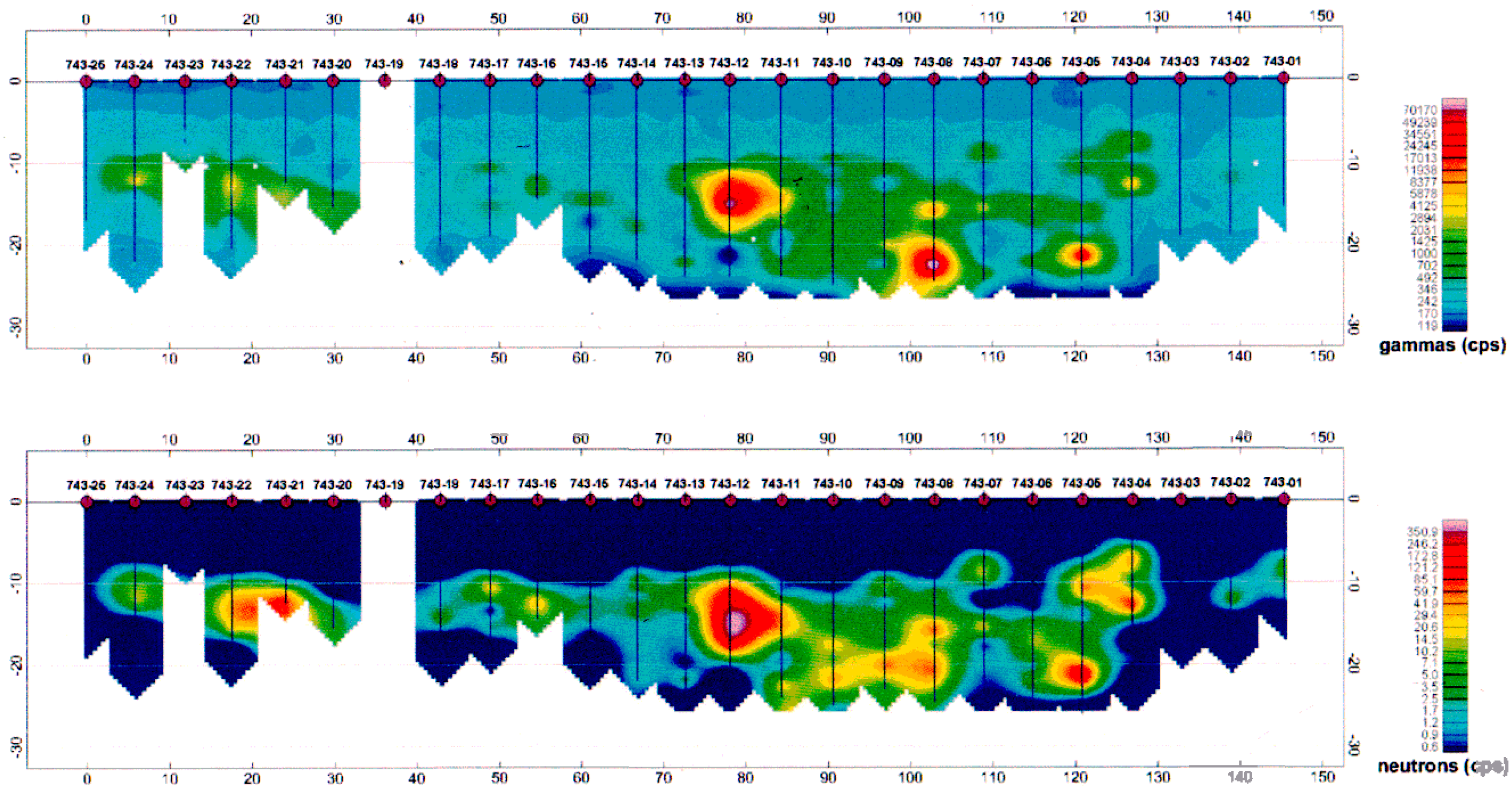

Figure 3-8. Gross gamma ray (top) and gross neutron (bottom). Note logarithmic color scale.

- The top of the high-chlorine zone ranges from 5 ft below ground surface at the north end of the transect to 10 ft below ground surface in the central portion of the transect. The thinned overburden on the north end may contribute to the observed high soil gas.

- The bottom of the chlorine zone corresponds to the bottom of the probes through the central portion of the transect, but some "clean" underburden is observed at the north and south ends.

- The 6,111 keV:1,168 keV gamma-ray ratio shows a high trend (>0.7) along the top of the chlorine zone but is otherwise fairly constant at 0.4–0.5. This observation is consistent with the greater penetration of 6,111 keV gamma rays relative to 1,168 gamma rays.

- Moisture log data shows low apparent moisture throughout the same area having high chlorine. This is attributed to the neutron-absorbing capacity of chlorine, which causes the moisture tool to respond in the same manner as it responds to low moisture soils. Moisture log data clearly delineate the apparent bottom of the waste zone.

- Moisture content in the overburden appears to decrease at the south end of the profile, and it becomes difficult to identify the transition between overburden and waste.

- The n-gamma 2,223 keV response (indicative of hydrogen) shows trends similar to the moisture log but less pronounced and with a few exceptions: (a) n-gamma-H does not show the apparent decrease in overburden moisture content at the south end and (b) n-gamma-H shows a high hydrogen zone at 20–40 from the south end of the transect.

- Gross gamma and passive neutron data show sharp spatial variation in radiation field strength compared with the chlorine, hydrogen, and moisture data. Anomalous gamma and neutron radiation are observed throughout the high-chlorine zone and also at the southern end of the transect where low chlorine was noted. Overall, the gross gamma-ray and neutron data may indicate that radionuclide contamination is highly localized and discontinuous, but chlorine contamination is relatively uniform or slowly varying.

3.1.3 Quantitative Chlorine Mass Analysis

One of the objectives for the 743 Study Area is to utilize subsurface Type A probes and overburden soil gas survey data to produce an estimate of the total VOC mass remaining within the northeast portion of Pit 4. Initially, it is of particular interest to determine if subsurface waste zone VOCs (as represented by n-gamma chlorine logging measurements) bear a consistent relationship to soil gas distributions. New soil gas probes were installed along the probe transect and sampled during the summer of 2001. Figure 3-9 compares the raw n-gamma chlorine log response (in cps) against new soil gas sampling results. The approximate correlation between these data sets encouraged further investigation of methodologies to estimate VOC mass based on n-gamma chlorine data.

One suggested method for estimating total VOC mass is to use the n-gamma log data to establish a quantitative correspondence between subsurface waste layer chlorine and overburden soil gas. If successful, the soil gas data could then be used to roughly estimate chlorine mass distribution for areas without logging probes. This general VOC mass estimation concept is outlined schematically in Figure 3-10.

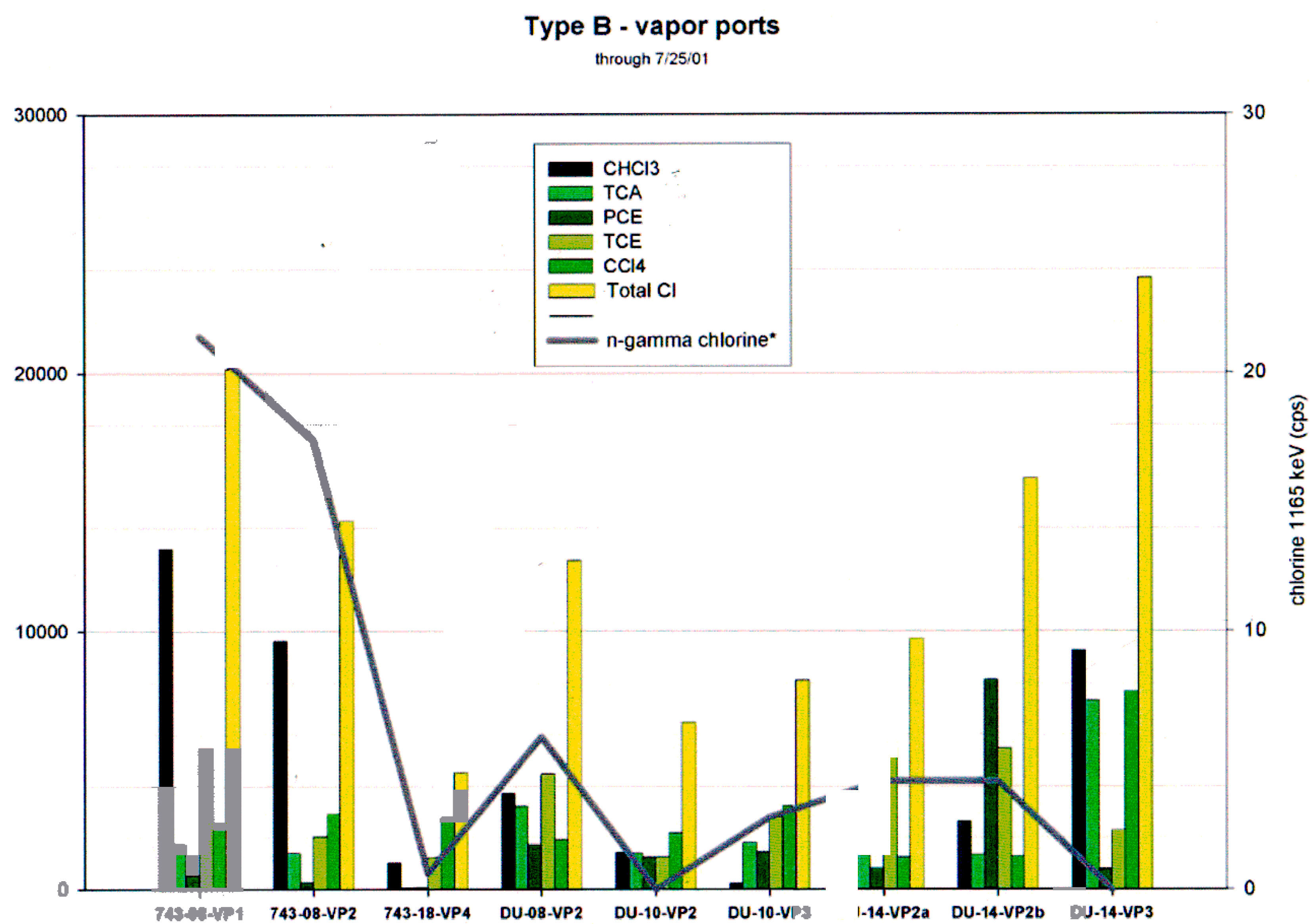

Figure 3-9. Comparison between n-gamma logging data and 2001 soil vapor survey results.

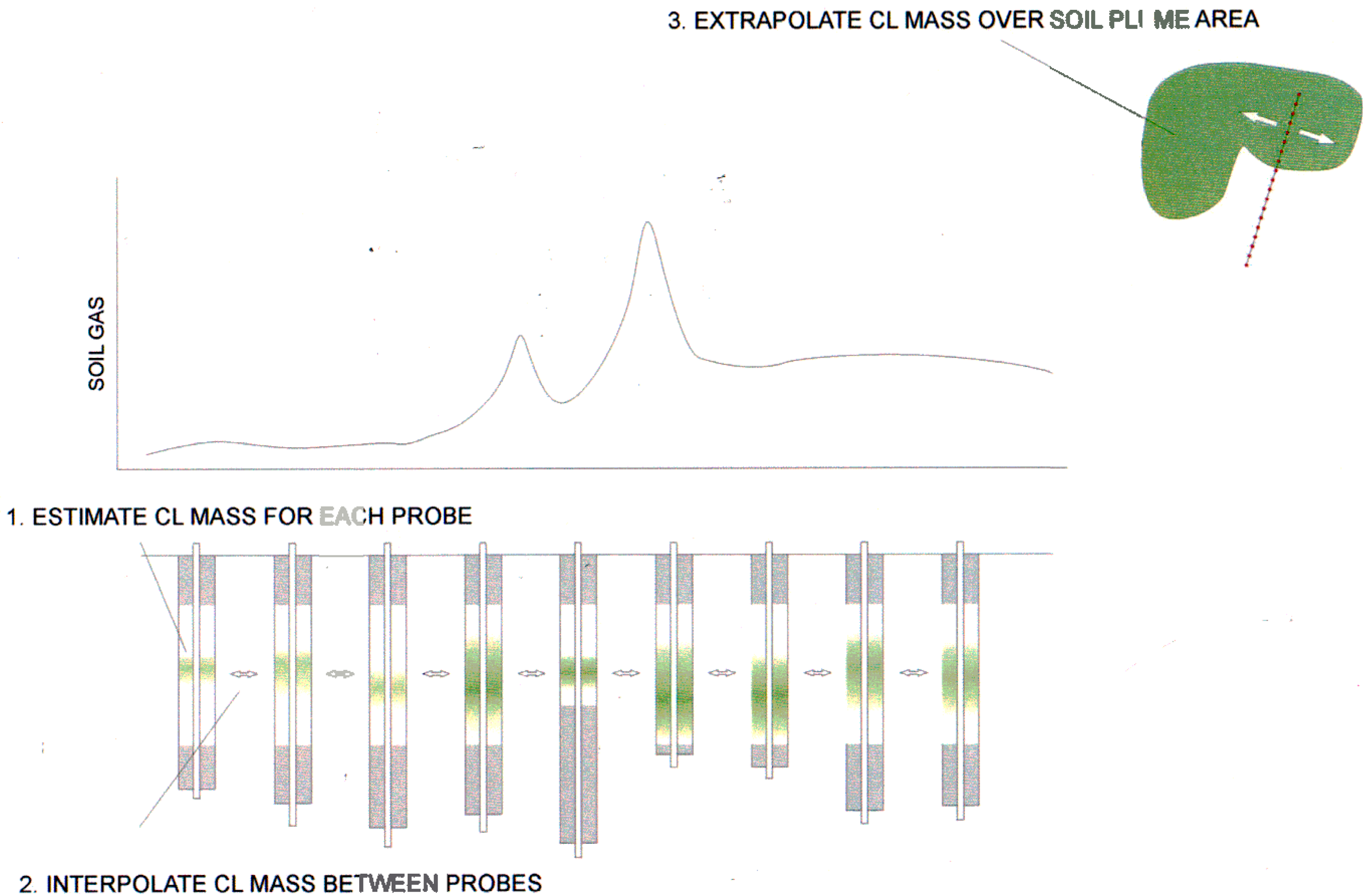

Figure 3-10. Schematic illustration of proposed volatile organic compound mass estimation method.

The downhole logging subcontractor estimates that the volume of investigation for subsurface chlorine detection extends no more than 6–12 in. from the bore hole wall under typical subsurface conditions. The 743 Study Area probe hole transect consists of 25 probe holes spaced on 6-ft centers. Even allowing for a 12-in. radius of investigation, logging measurements interrogate, at most, 35% of the subsurface volume intersected by the probe transect. The presence of chlorine between probes must, therefore, be interpolated. Furthermore, to estimate the VOC mass associated with the entire soil gas plume, transect estimates must be extrapolated to estimate chlorine mass beneath the portion of the soil gas plume not intersected by the probe transect. The assumptions inherent to steps two and three of the proposed VOC mass estimation method were considered to introduce appreciable uncertainty to the final result.

A second proposed VOC mass estimation approach was to use n-gamma chlorine data to calibrate waste inventory records, which contain information regarding the amount of original VOCs disposed in SDA pits and trenches. In this method, a VOC mass estimate was generated at each probe location using the inventory records database. This number was taken to represent the original amount of VOC mass. The n-gamma logging data was then used to develop an estimate of the VOC mass at the time of logging. The ratio of the two VOC mass values provides an estimate of the residual VOC mass. This ratio would then be applied to all inventory records data to arrive at a final value for the current VOC mass. A full development of this approach is provided in a report (Miller, Sondrup, and Josten 2002). The following sections were developed as a preliminary step.

3.1.3.1 Estimates of Original Carbon Tetrachloride Mass. Current carbon tetrachloride (CT) mass estimates are based on inventory records that list the number of Rocky Flats Plant (RFP) 743-series drums shipped to INEEL (Table 3-1). The original 1987 and 1995 estimates were based on monthly shipping reports, which listed a large number of drums for which CT content was not specified, and these drums were assumed to contain no CT. Miller's updated estimates assume that these drums contained CT and that the average CT content in them was identical to the average CT content for other drums. Miller's three separate estimates are all based on the same fundamental assumptions.

The inventory records also contain an approximate location for each waste shipment. Using the CT and location information contained in the records, a 55-gal drum density map was generated for the 743 Study Area. An estimate of the original CT mass at each probe location was determined using drum density maps, an average value for CT mass per drum, and an estimate of the n-gamma logging volume of investigation around each probe.

Table 3-1. Carbon tetrachloride mass estimates based on waste inventory records.

Year	Author	Method	CCL_4 mass (kg)
1987	Kudera	Monthly reports describing drum contents	1.50×10^5
1995	LMITCO	Monthly reports describing drum contents	1.20×10^5
1998	Miller	Total 743 drum count and average CCl_4 content	4.85×10^5
1998	Miller	Total 743 drum count and volumetric capacity	5.10×10^5
1998	Miller	Total 743 drum count and average drum weight	4.72×10^5

LMITCO = Lockheed Martin Idaho Technologies Company

3.1.3.2 Estimates of Current Carbon Tetrachloride Mass From Logging Data. Using the measured n-gamma chlorine (1,165 keV) logging data as a starting point, mass values were determined for each 743 Study Area probe hole. The computation steps are outlined below:

1. Logging data give a count rate for the chlorine 1,165 keV capture gamma. This value is measured every 0.5 ft beginning at 1 ft below the ground surface and continuing to basalt (i.e. refusal).

2. Form a right vertical cylinder with a radius of 1 ft, centered on the probe hole, and extending from the surface to refusal.

3. Subdivide this cylinder into a stack of smaller cylinders, each subcylinder having its top and bottom at successive measurement depths (Figure 3-11).

4. Calculate the chlorine mass contained in each subcylinder as follows:

$$m_{Cl} = f_{GTS}\left(cps_{Cl\_1165}\right) * m_{sub-cylinder} * \frac{m_{CT}}{m_{Cl}} \quad (1)$$

where

f_{GTS}	=	logging subcontractor estimated calibration function
$cps_{1165\ keV}$	=	measured n-gamma count rate at bottom of each subcylinder
$m_{sub\text{-}cylinder}$	=	subcylinder mass and is determined assuming a 1.7 g/cc bulk density within the entire subcylinder volume
m_{CT}/m_{Cl}	=	ratio of CT to total chlorine mass for Rocky Flats 743 sludge.[a]

5. Add chlorine mass from all subcylinders for each probe.

Table 3-2 compares the logging-based CT estimates with estimates obtained based on inventory data. Some inventory-based estimates were not available at this preliminary analysis stage.

These data suggest that the amount of CT mass within the study area has been reduced by an average of 80% due to volatilization and migration. Due to the potential importance of this conclusion, this preliminary effort was followed up by more in-depth study including uncertainty analysis (Miller, Sondrup, and Josten 2002). Table 3-3 lists the principal uncertainty sources for the logging-based CT mass estimates.

[a] Based on the 743-series waste report, CT accounts for 75% of all VOCs in RFP 743 sludge (Miller and Varvel 2001). The other 25% is a mixture of trichloroethane, trichlorethene, and tetrachloroethylene, which is assumed to occur in equal proportions. Using molecular formulas for CT, trichloroethane, trichlorethene, and tetrachloroethylene and atomic weights for chlorine, carbon, and hydrogen, it was found that there are 0.85 g of CT for every 1 g of chlorine in the 75–25% VOC mixture. Thus, $m_{CT}/m_{Cl} = 0.85$.

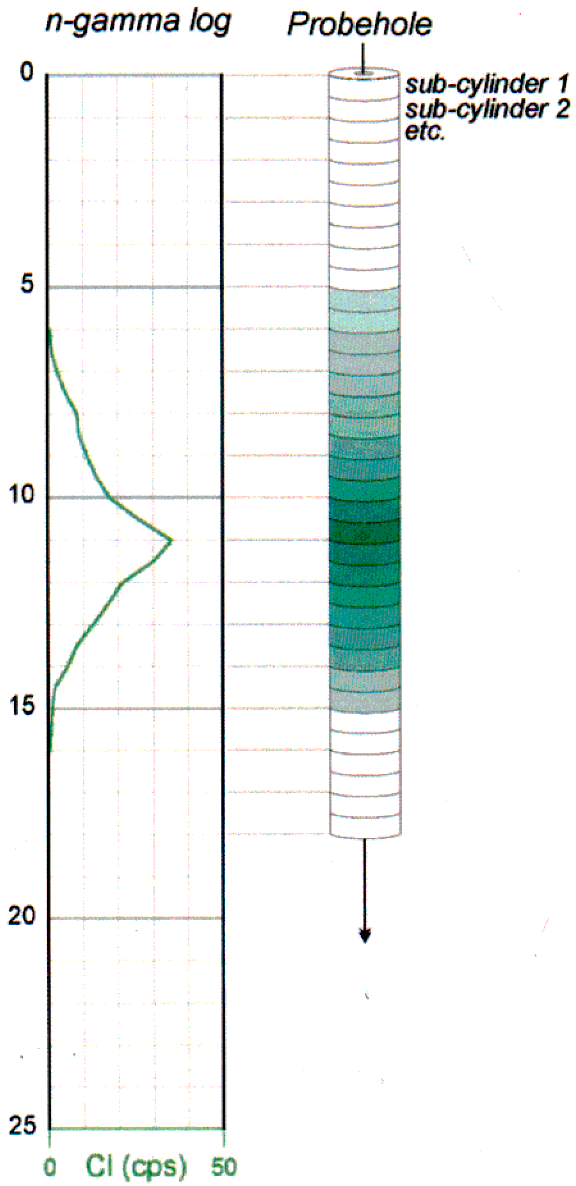

Figure 3-11. Method for estimating volatile organic compound mass for a single probe.

Table 3-2. Comparison of carbon tetrachloride mass estimates for 743 sludge probes.

	Carbon Tetrachloride Mass (kg)		
Probe ID	Inventory	Logging	%
743-01	288.7	6.5	2%
743-02	9.5	16.4	173%
743-03	36.3	18.3	50%
743-04	36.3	26.5	73%
743-05	NE	36.1	NE
743-06	NE	51.4	NE
743-07	153.0	37.9	25%
743-08	103.4	35.3	34%
743-08-01	NE	31.8	NE
743-08-02	NE	25.1	NE
743-08-03	NE	34.6	NE
743-08-04	NE	22.6	NE
743-08-05	NE	29.9	NE
743-08-06	NE	21.3	NE
743-09	83.8	38.6	46%
743-10	109.8	32.8	30%
743-11	174.4	25.3	15%
743-12	311.4	34.6	11%
743-13	216.4	38.2	18%
743-14	12.4	21.3	172%
743-15	NE	21.3	NE
743-16	68.7	10.7	16%
743-17	26.1	6.0	23%
743-18	13.4	2.6	19%
743-19	35.6	NE	NE
743-20	35.6	1.8	5%
743-21	NE	0.0	NE
743-22	NE	1.4	NE
743-23	NE	0.0	NE
743-24	NE	0.9	NE
743-25	NE	0.0	NE

Table 3-2. (continued).

Probe ID	Carbon Tetrachloride Mass (kg) Inventory	Logging	%
743-32	188.6	0.5	0%
743-33	74.5	0.0	0%
743-34	22.3	0.0	0%
743-35	147.3	0.1	13%
743-36	53.9	19.7	45%
743-37	6.5	24.4	149%
743-38	NE	9.6	NE
743-39	NE	3.0	NE
743-40	NE	21.4	NE
743-41	NE	4.8	NE
743-42	NE	2.5	NE

NE = no estimate

Table 3-3. Uncertainty sources for logging-based carbon tetrachloride mass estimates.

Source	Description	+/-
Tool calibration	Tool saturates at some unknown chlorine level	Increase some estimates
High hydrogen	Hydrogen-rich volatile organic compounds will moderate neutrons and effectively move 1,165 keV "source" further from detector (calibration assumption is 7 vol% H_2O)	Increase some estimates
Density	Low density sludge will cause reduced gamma-ray attenuation compared with the calibration assumption of 1.8 g/cc soil	Decrease some estimates
Heterogeneity	Mass calculation model assumes uniform distribution, but actual source may be heterogeneous	May increase or decrease some estimates

3.1.4 Observations on Radionuclide Contamination

The logging subcontractor conducted preliminary processing of the 741 Study Area logging data. Their processing included automated spectral analysis of passive gamma-ray data to identify the presence of specific target contaminants, including ^{235}U, ^{238}U, ^{239}Pu, ^{241}Am, and ^{237}Np. After applying a standard calibration correction to convert net count rates to apparent radionuclide concentrations, summary results were compiled and delivered to the INEEL along with the raw spectral data.

Table 3-4 gives maximum detected levels of key target contaminants for all 743 Area probes. Blank cells indicate nondetects.

Table 3-4. Summary of logging results for 743 Sludge Study Area probes.

Well ID	Gross Count Rate	^{235}U (pCi/g)[a]	^{238}U (pCi/g)[a]	^{239}Pu (nCi/g)[a]	^{233}Pa (pCi/g)[a]	^{241}Am (nCi/g)[a]	^{137}Cs (pCi/g)[a]	^{60}Co (pCi/g)[a]	Cl_1165 (cps)
743-01	360	ND	ND	70.3	ND	ND	ND	ND	15.1
743-02	467	3.9	ND	205.5	ND	46.9	ND	ND	26.9
743-03	296	ND	ND	137.0	ND	ND	ND	ND	35.3
743-04	5,792	ND	9.7	1,503.0	108.3	3,373.0	ND	ND	29.7
743-05	33,869	ND	103.3	1,630.0	ND	10,467.0	ND	ND	26.6
743-06	2,367	ND	ND	2,168.0	8.9	271.6	ND	ND	29.9
743-07	2,986	19.4	1,582.0	280.2	14.4	544.6	ND	ND	21.6
743-08	136,246	344.9	220,894.0	9,005.0	58.4	1,857.0	ND	ND	29.5
743-08-01	8,397	24.2	6,899.0	173.5	22.3	655.6	6.0	ND	18.0
743-08-02	67,001	6.9	11,862.0	17,466.0	1,013.0	30,449.0	ND	ND	15.7
743-08-03	10,947	ND	5,861.0	6,439.0	110.2	4,488.0	ND	ND	22.6
743-08-04	40,874	9.2	444.1	35,859.0	76.2	4,494.0	ND	ND	16.2
743-08-05	13,262	ND	5,694.0	8,663.0	38.6	1,198.0	ND	ND	27.8
743-08-06	143,147	251.1	206,269.0	479.6	21.2	750.7	6.9	ND	15.0
743-09	3,289	ND	329.9	1,547.0	36.8	1,242.0	ND	ND	26.8
743-10	1,886	13.9	714.1	962.5	13.7	477.4	ND	ND	32.0
743-11	7,220	20.4	1,064.0	5,958.0	49.4	2,048.0	ND	0.3	22.7
743-12	86,729	62.7	ND	72,259.0	275.2	8,160.0	ND	0.3	19.7
743-13	1,560	6.5	113.7	1,055.0	5.3	230.6	ND	ND	26.4
743-14	535	35.1	50.4	67.2	1.1	119.6	ND	ND	27.4
743-15	1,163	21.2	ND	1,105.0	ND	106.4	ND	ND	22.3
743-16	1,683	ND	ND	1,098.0	ND	162.0	ND	ND	17.1
743-17	632	ND	177.2	292.4	1.1	89.3	ND	ND	8.7
743-18	327	ND	ND	135.3	ND	ND	ND	ND	4.6
743-20	1,439	ND	7,36.9	602.0	ND	142.8	ND	ND	3.8
743-21	1,847	ND	ND	763.4	ND	102.0	ND	ND	ND
743-22	4,175	ND	ND	4,355.0	ND	341.1	ND	ND	2.3
743-23	224	ND	ND	ND	ND	ND	ND	ND	ND
743-24	4,215	ND	ND	3,531.0	11.5	466.0	ND	ND	2.2
743-25	246	ND	ND	ND	ND	ND	ND	ND	ND
743-32	224	ND	ND	ND	ND	33.9	ND	ND	2.6
743-33	216	0.5	ND	ND	ND	ND	0.3	0.3	0.3
743-34	218	ND	ND	ND	ND	ND	0.3	ND	ND
743-35	1,996	ND	ND	ND	8.3	732.3	ND	ND	0.9
743-36	24,406	1,07.9	840.2	13,887.0	31.6	1,466.0	ND	ND	17.4
743-37	115,174	ND	ND	89.8	ND	ND	ND	ND	23.6
743-38	289	ND	ND	117.2	ND	ND	ND	ND	15.6
743-39	3,447	3.7	98.4	3,061.0	16.0	504.8	ND	ND	9.2
743-40	281	0.5	11.3	97.9	ND	ND	ND	ND	28.4
743-41	264	6.7	32.9	ND	ND	28.8	ND	ND	7.0
743-42	276	9.8	ND	ND	ND	ND	0.7	ND	4.1

a. Assumes homogenous, isotropic, and unconsolidated soil media.

ND = nondetect

Extensive chlorine contamination is observed in the northern half of the study area, generally reflecting the location of a previously observed soil gas plume. Pu, Am, and Np contamination is observed across the area, but Am and Np levels are much lower relative to Pu than was observed in the 741 Study Area.

Chlorine concentrations diminish toward the northern Pit 4 boundary. In situ vitrification probes (743-34–743-42) show some high-chlorine levels comparable to transect probes and some low-chlorine (or nondetect) levels due presumably to the northern limit of waste. Both the 1,165- and 6,111-keV chlorine lines present the same general picture of chlorine distribution (see Figure 3-12).

3.1.4.1 Plutonium, Americium, and Neptunium. Pu, Am, and Np are observed in various combinations throughout the 743 Study Area. Probe 743-12 shows an apparent ^{239}Pu concentration of 72,259 nCi/g, about 33% of the level observed in Probe P9-20. Possible interference between Pu and Np gamma rays (414 keV and 416 keV, respectively) was not evaluated by the logging subcontractor and could lessen the apparent concentration of Pu.

Pu:Am and Am:Np apparent activity ratios for 743 Area probes are shown in Figure 3-13. Computed ratios assume homogenous conditions and do not account for differential attenuation of gamma rays.

3.1.4.2 Uranium-235 and Uranium-238. Throughout the central portion of the main transect (743-05–743-17), ^{238}U and ^{235}U are observed. Probe 743-08 shows an apparent ^{238}U concentration of 220,894 pCi/g, which is an order of magnitude higher than the previous highest ^{238}U probe (depleted uranium [DU-14]) and two orders of magnitude greater than the highest levels observed elsewhere in the 743 area.

Figure 3-13 shows ^{238}U:^{235}U apparent activity ratios for 743 Study Area probes. Computed ratios assume homogenous conditions and do not account for differential attenuation of gamma rays.

3.1.4.3 Thorium. GTS Duratek noted elevated 2,614 keV gamma-ray counts in many of the central and northern transect probes. Probe 743-37 shows the highest levels. Elevated 583- and 511-keV counts were also reported. These gamma rays are associated with ^{208}Tl. By tracing upward through the ^{208}Tl decay chain, it appears that the anomalous source is ^{228}Th. The possible cause of excess ^{228}Th is not readily apparent and a detailed inventory review has not yet been conducted. GTS Duratek reports additional unidentified gamma rays in probes having ^{208}Tl gammas. These unidentified gamma rays may help to determine some of the characteristics of the ^{228}Th waste.

3.1.5 Azimuthal Logging Data Analysis

The Operable Unit (OU) 7-13/14 project conducted azimuthal gamma-ray logging in selected probes within the 743 Study Area as a means to investigate the spatial distribution of subsurface radionuclides. Two probes were selected for the azimuthal surveys based on existing geophysical logging data. These probes were selected because they contained high levels of either ^{238}U or ^{237}Np (Table 3-5).

Azimuthal logging was conducted by GTS Duratek during May 2001, and preliminary results were delivered to the INEEL on May 31, 2001. Azimuthal logs were analyzed to choose probes for follow-up studies of ^{238}U or ^{237}Np leaching and migration. Azimuthal data were used to indicate the position of ^{238}U or ^{237}Np relative to the probe hole so that lysimeters could be installed to collect leachate samples.

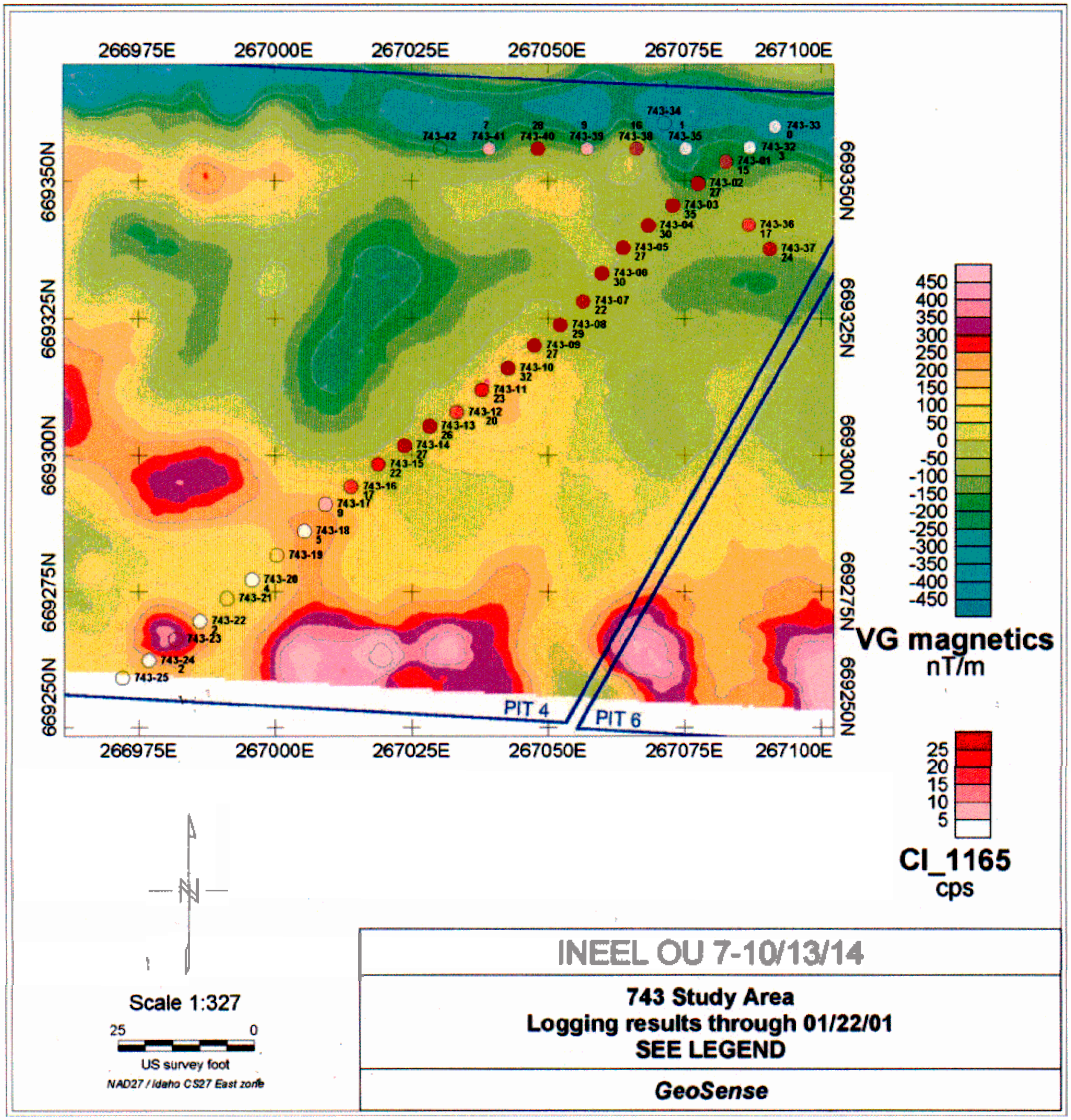

Figure 3-12. Chlorine_1,165 keV logging results compared with surface geophysics.

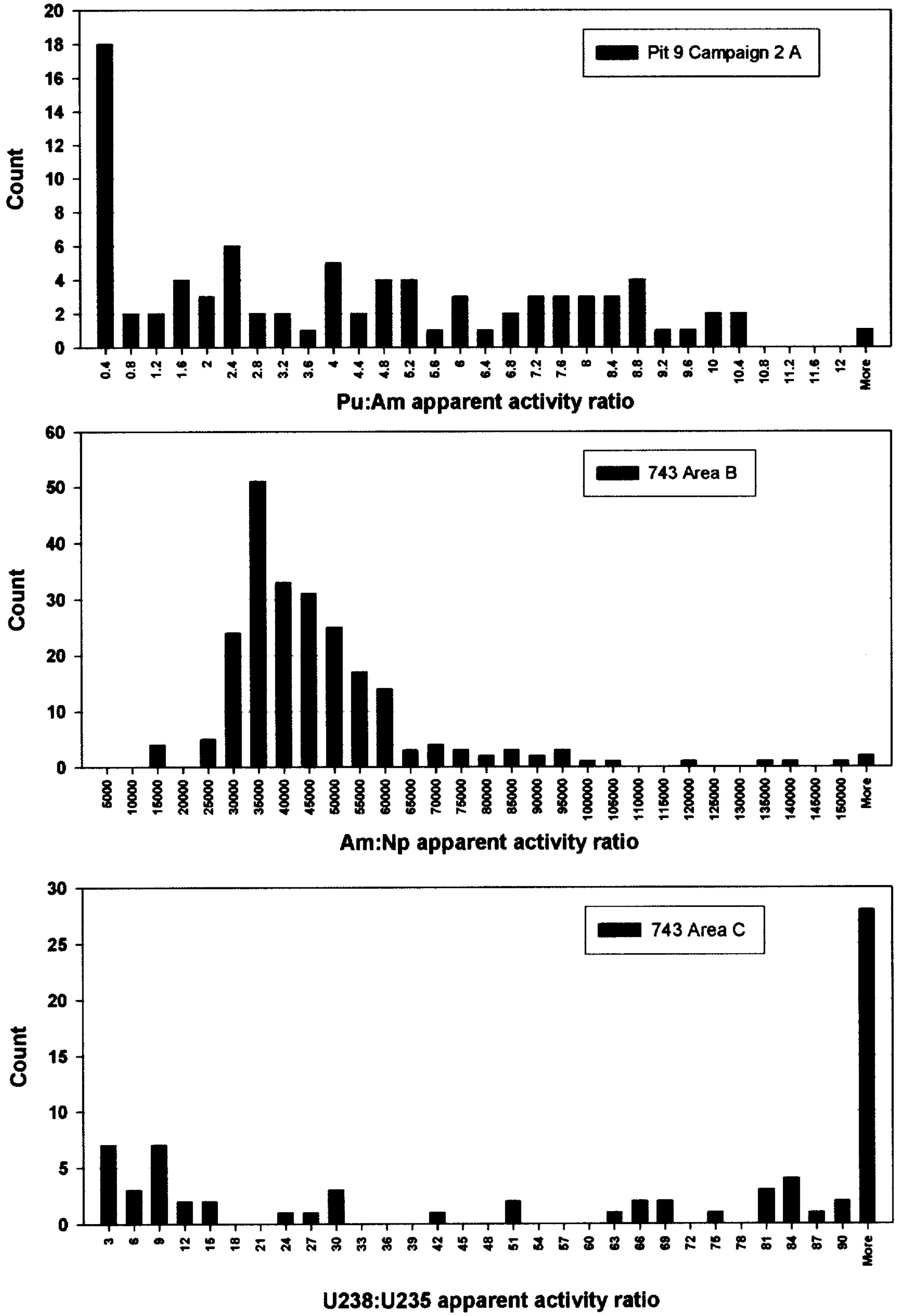

Figure 3-13. Histogram of isotopic ratios for 743 Study Area probes.

Table 3-5. 743 Sludge Study Area probe holes selected for azimuthal logging.

Probe Hole	Depth (ft)	Radionuclide	Max cps[a]
743-08	22.5	^{238}U	220894
743-12	15.5	^{237}Np[b]	275

a. As observed by standard gamma-ray logging.

b. ^{237}Np indicated by ^{233}Pa daughter.

For each probe, Table 3-6 lists detected radionuclides and gives the azimuth of the observed maximum count rate for each. Azimuth is measured with respect to a north arrow marked on the probe casing. Table 3-6 also gives the approximate maximum count rates and two general qualifiers. The first qualifier describes the statistical significance of the direction indication, and the second qualifier describes the narrowness of the direction indication (i.e. "good" indicates a highly directional source, and "poor" indicates a broadly directional source).

Table 3-6. 743 Sludge Study Area azimuthal data summary.

Probe	Depth (ft)	Nuclide azimuth	Maximum cps	Statistics	Direction
743-08	22.5	^{238}U @ 200 degrees	120	Good	Poor
		^{235}U @ NA	2.5	Poor	Poor
743-12	15.5	^{239}Pu @180 degrees	29	Good	Poor

3.1.6 Cluster Probe Analysis

A cluster of six probes was installed in the vicinity of Probe Hole 743-08 in order to investigate the large ^{238}U source at 22.5 ft. The probe cluster was designed based on a conceptual model of the measurement environment within the waste layer. Nuclear logging methods have a relatively limited volume of investigation (~0–1 ft). The logging tool may pass through or alongside one or more source volumes (such as contamination bearing 55-gal drums) during logging operations in any probe. The logging instruments will record increased gamma-ray activity only if some part of a source volume occurs within the volume of investigation of the logging tool. For purposes of this interpretation, we assume that the measured logging response at any given depth is influenced by a single source distribution having a total volume less than or equal to the volume of a 55-gal drum (~9 ft^3).

The recommended cluster probe geometry consists of six equally spaced probes forming a ring around the probe of interest (Figure 3-14). The cluster probe pattern has a footprint of 3 × 3 ft and is well suited to intersect and surround a target volume of 9 ft^3. In addition, the spacing between probes is 1.5 ft so that the volume of investigation for adjacent probes will intersect slightly.

The "spiral" cross section in Figure 3-15 depicts a complex distribution of Pu, Am, and Np; ^{235}U and ^{238}U; and chlorine that occurs within the 743-08 cluster probes. The 743-08 area is interpreted to contain at least five separate radionuclide sources in the depth range of 9–25 ft. Chlorine permeates the entire volume. From bottom to top, the sources may be characterized as given in Table 3-7.

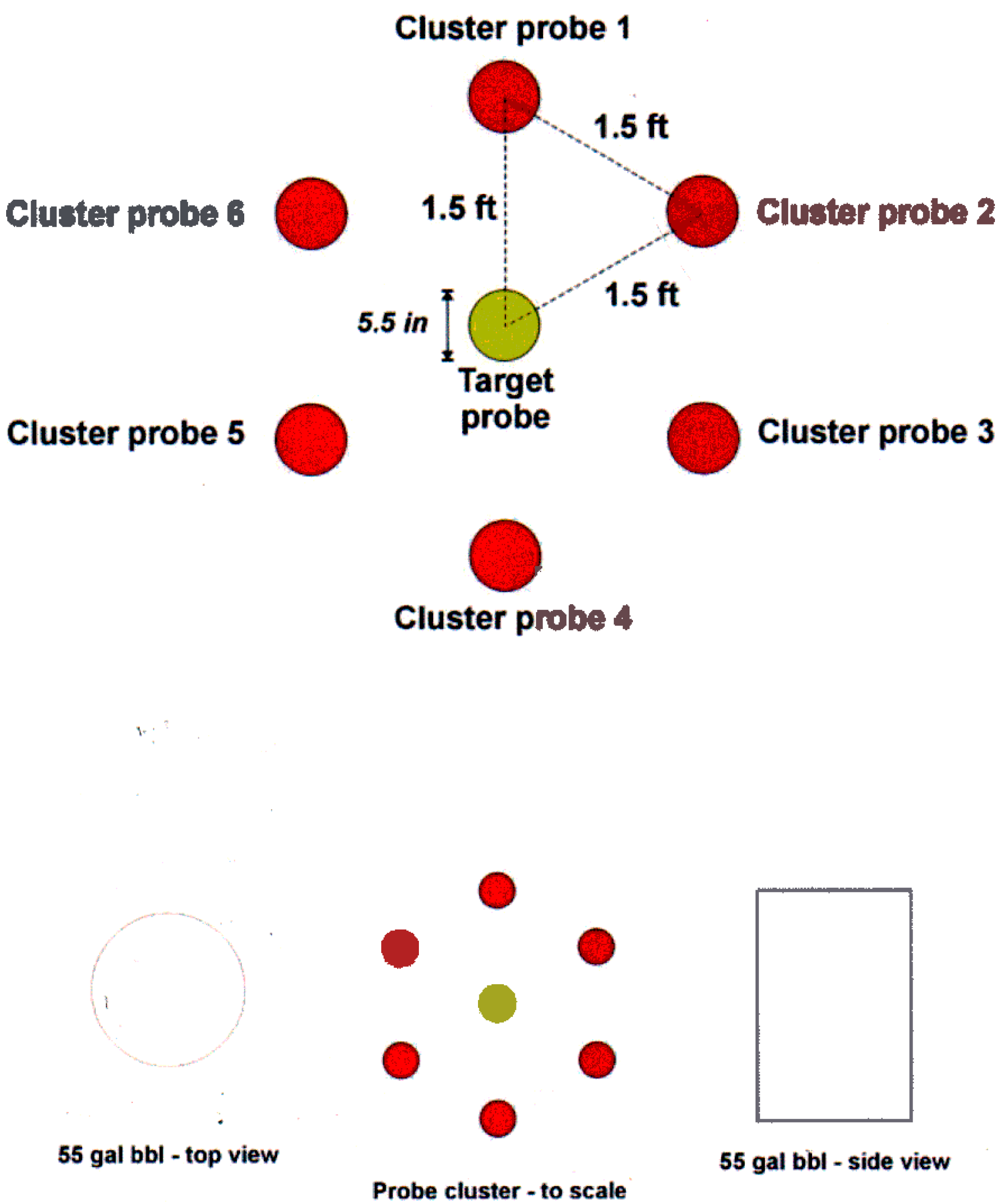

Figure 3-14. Cluster probe geometry.

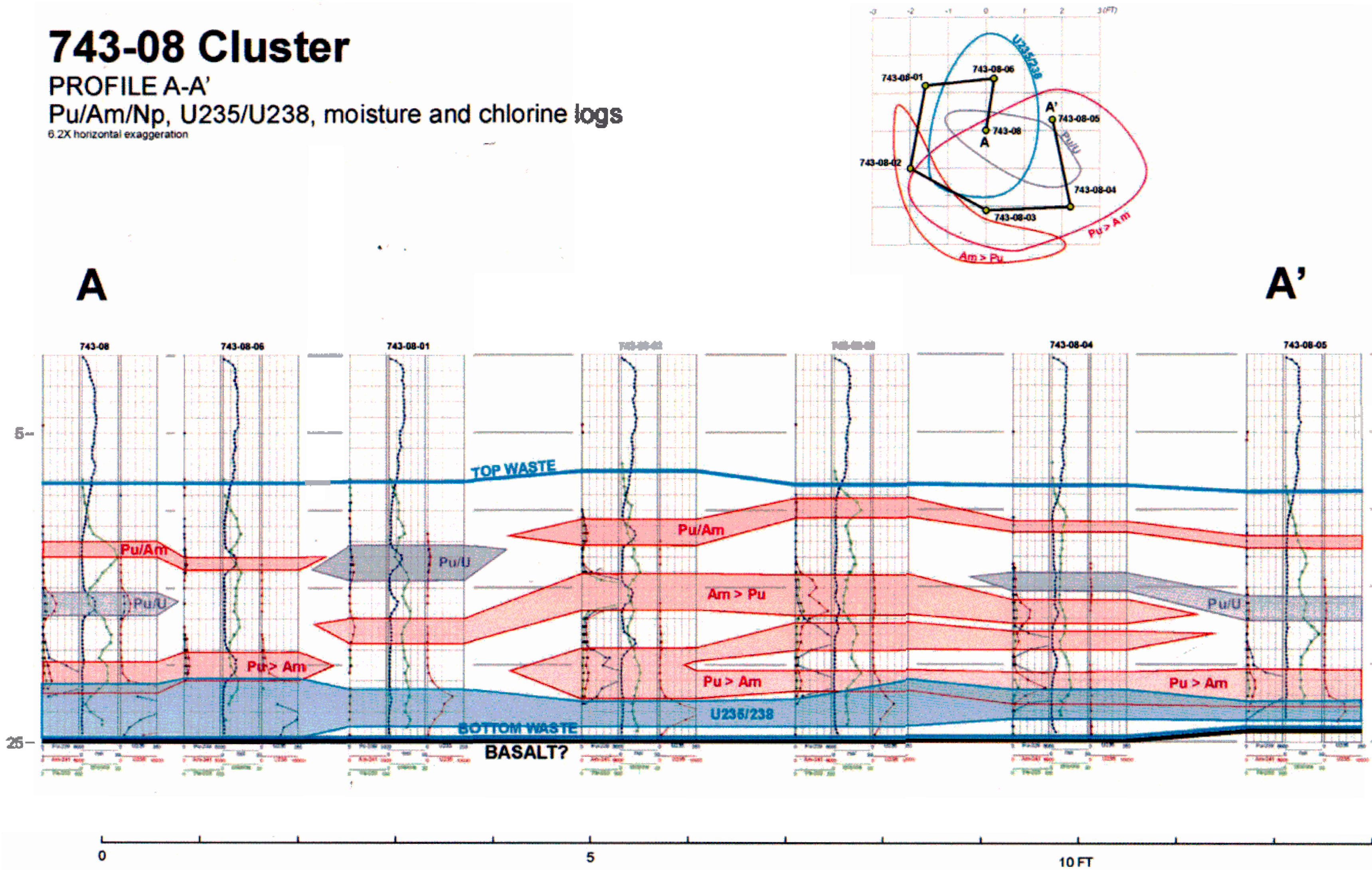

Figure 3-15. Spiral cross section through the 743-08 cluster probe.

Table 3-7. Interpreted waste zones in the 743-08 cluster probe area.

Depth Range	Description
21–25 ft (near basalt)	High level ^{235}U and ^{238}U zone
17–22 ft	High level Pu, Am, and Np; Pu > Am
14–18 ft	Moderate level Pu, Am, and Np; Am > Pu
12–17 ft	Moderate level mixed Pu and U
9–14 ft	Low level Pu, Am, and Np; Pu > Am

3.2 741 Sludge Focus Area

The primary goal of the 741 Sludge Focus Area investigation is to assess the solubility of ^{237}Np and determine its potential for transport in groundwater. To evaluate solubility, nuclear logging data is used in combination with leachate samples collected in the vicinity of a known ^{237}Np source. A groundwater release model is then constructed to simulate the relationship between an ^{237}Np source (determined from logging data) and dissolved ^{237}Np in groundwater (determined from leachate samples) under a set of known (or estimated) soil moisture conditions (Figure 3-16). These models provide an estimate of ^{237}Np solubility and release potential.

3.2.1 Selection of Probe Locations

Figure 3-17 shows surface geophysical data used for selecting probe locations in the 741 Sludge Focus Area. The inventory data showed a concentration of RFP 741-series sludge drums in the west-central portion of Pit 10. Geophysical data were interpreted to indicate the location of concentrated metallic debris, such as 55-gal drums. Accordingly, the 741 Focus Area exploratory probes were arranged as two profiles and positioned to intersect geophysical anomalies within the 741 drum area.

3.2.2 Observations on Radionuclide Contamination

The logging subcontractor conducted preliminary processing of the 741 Study Area logging data. Their processing included automated spectral analysis of passive gamma-ray data to identify the presence of specific target contaminants including ^{235}U, ^{238}U, ^{239}Pu, ^{241}Am, and ^{237}Np. After applying a standard calibration correction to convert net count rates to apparent radionuclide concentrations, summary results were compiled and delivered to the INEEL along with the raw spectral data.

Table 3-8 summarizes maximum observed levels for radionuclide contaminants in the 741 Sludge Focus Area. Blank cells indicate nondetects. Note that the indicated concentrations should be viewed as "apparent" concentrations and are accurate estimates if the actual radionuclides are homogenously distributed within a soil media.

The 741 area is characterized by a well-defined 3–5-ft-thick Pu, Am, and Np contamination zone with its top located at 7–9 ft below ground surface (see Figure 3-18). Chlorine contamination occurs throughout and, in some cases, extends well below the radionuclide contamination zone. Isotopic ratios indicate both Am and Np enrichment relative to the amounts of these radionuclides that would be expected from pure Pu decay. Cesium-137 was identified in Probe Hole 741-4 at a depth interval from 13 to 20 ft with a maximum concentration of 139.4 pCi/g at a depth of 16.5 ft.

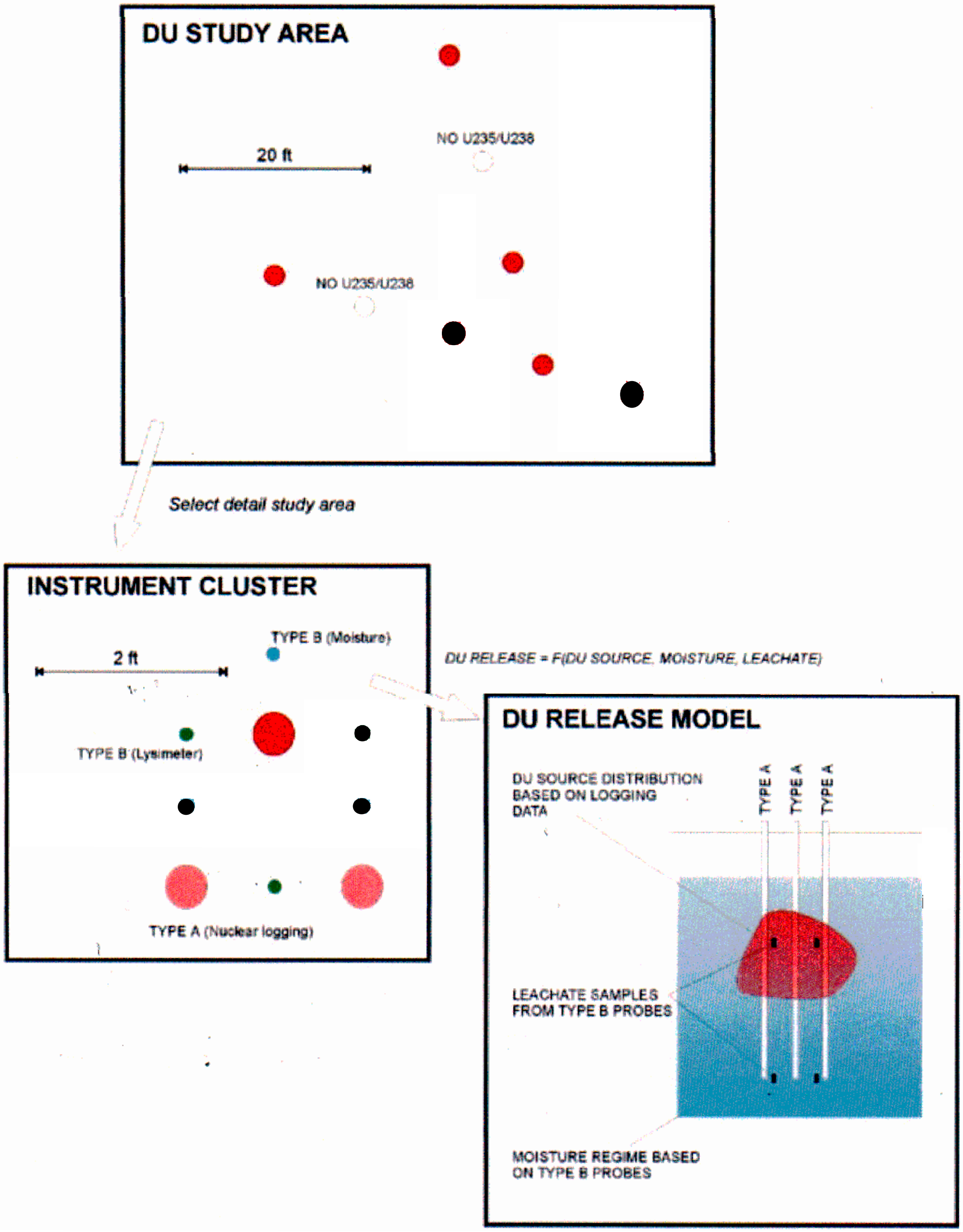

Figure 3-16. Illustration of the use of a groundwater release model based on logging data and leachate samples.

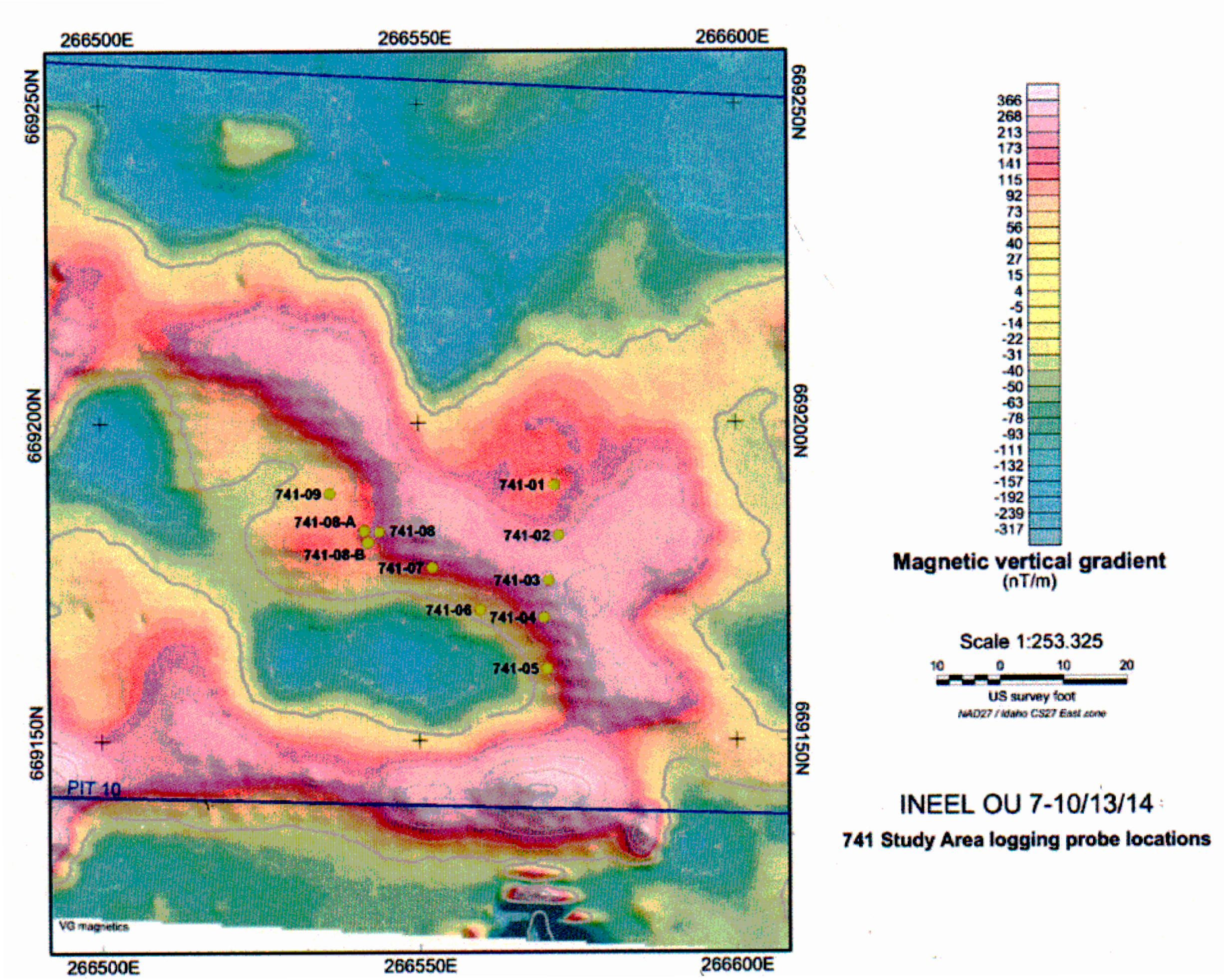

Figure 3-17. Inventory and geophysical data for 741 Sludge Focus Area. Final probe locations are also shown.

Table 3-8. Radionuclide detection summary for 741 Sludge Focus Area.

Well ID	Count Rate	^{235}U (pCi/g)[a]	^{238}U (pCi/g)[a]	^{239}Pu (nCi/g)[a]	^{233}Pa (pCi/g)[a]	^{241}Am (nCi/g)[a]	^{137}Cs (pCi/g)[a]	^{60}Co (pCi/g)[a]	Cl_1165 (cps)
741-02	20,122	ND	ND	2,084.0	428.0	1,4338.0	ND	ND	7.8
741-03	12,504	ND	29.7	782.1	243.8	7,938.0	ND	ND	7.7
741-04	15,633	ND	ND	1,065.0	171.8	5,509.0	140.5	ND	2.4
741-06	4,496	83.9	681.0	1,504.0	72.0	2,386.0	ND	ND	2.8
741-08	20,325	ND	ND	8,407.0	315.8	9,136.0	ND	ND	9.7
741-08-A	233	15.6	ND	48.9	ND	ND	ND	ND	2.6
741-08-B	248	20.2	ND	ND	ND	ND	ND	ND	6.9
741-09	577	28.4	267.0	ND	ND	ND	0.7	0.1	4.4

a. Assumes homogenous, isotropic, and unconsolidated soil media.

ND = nondetect

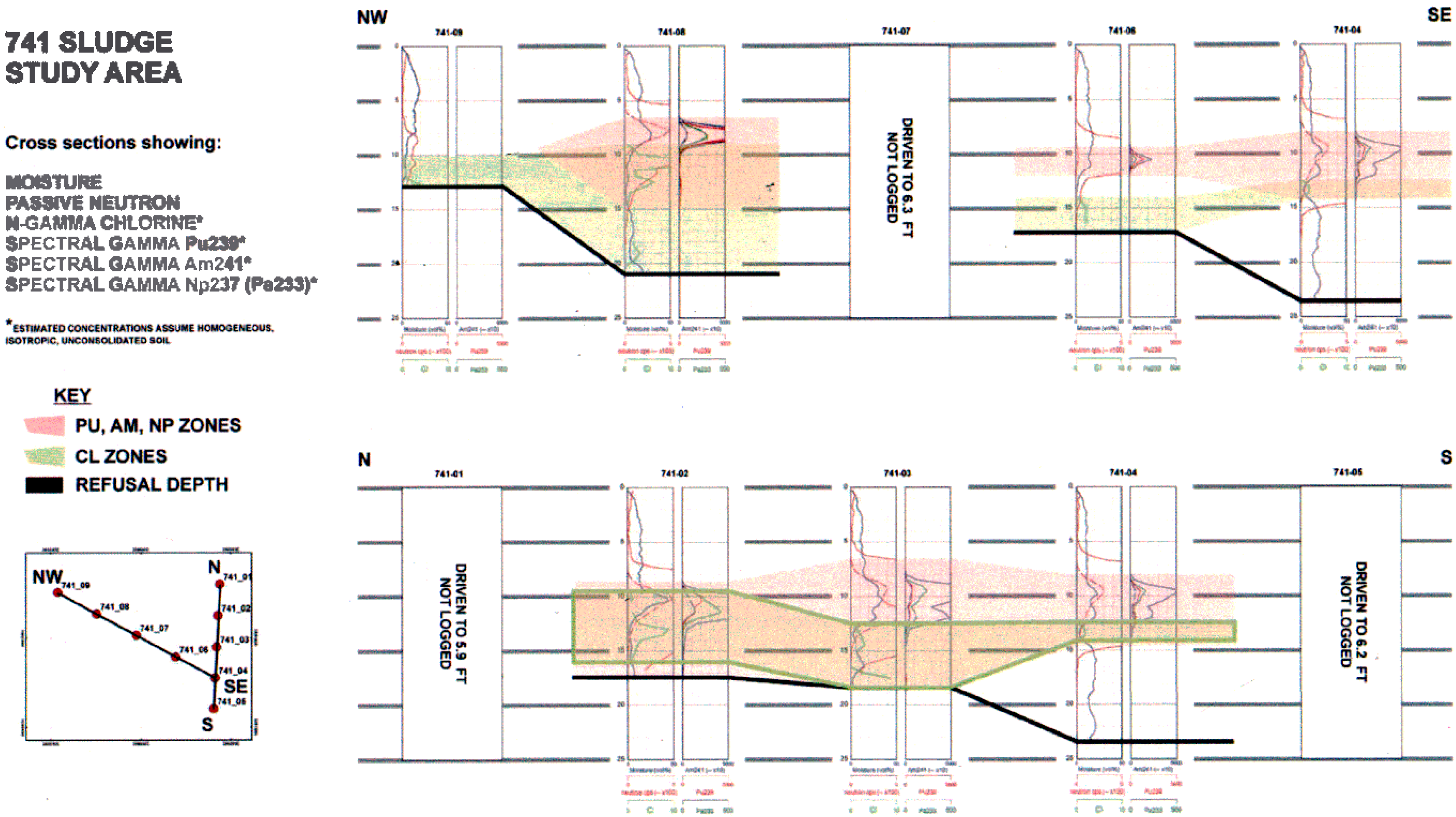

Figure 3-18. Cross section summary for the 741 Focus Area.

Two 741 Study Area probe holes were selected for further study. The primary recommended study target occurs in Probe Hole 741-08 at a depth of 8 ft. This zone has the following attributes:

- Pu, Am, and Np observed in high concentrations compared with other 741 Area probe holes
- Single, narrow Pu, Am, and Np contamination zone with no other intermixed contamination observed
- Zone shows significant ^{237}Np enrichment relative to the amount expected from the decay of pure ^{241}Am
- Reduced contamination level for 10 ft below high-contamination zone provides convenient conditions for leachate collection and migration studies.

The secondary recommended study target in the 741 Study Area occurs in Probe Hole 741-02 at a depth of 10.5–11.5 ft. This zone has the following attributes:

- Pu, Am, and Np observed in high concentrations compared with other 741 Area probe holes
- Single, broad Pu, Am, and Np contamination zone with no other intermixed contamination observed
- Zone shows significant ^{237}Np enrichment relative to the amount expected from the decay of pure ^{241}Am
- Reduced contamination level for 5 ft below high contamination zone provides convenient conditions for leachate collection and migration studies.

3.2.2.1 Plutonium, Americium, and Neptunium. Pu:Am and Am:Np apparent activity ratios for 741 Area probes are shown in Figure 3-19. Computed ratios assume homogenous conditions and do not account for differential attenuation of gamma rays.

Table 3-9 shows a comparison between expected and observed Pu, Am, and Np ratios where the expected values are based on 30 year decay of weapons-grade plutonium. The observed Am and Np values indicate enrichment of both ^{241}Am and ^{237}Np relative to Pu for this specific decay scenario.

3.2.2.2 Uranium-235 and Uranium-238. Figure 3-19 shows ^{238}U:^{235}U apparent activity ratios for 741 Study Area probes. Computed ratios assume homogenous conditions and do not account for differential attenuation of gamma rays.

Enriched or highly enriched uranium was identified in Probe Holes 741-6 and 741-9. These zones were identified in narrow intervals near the bottoms of the probe holes, separate from any ^{241}Am or ^{237}Np.

3.2.3 Azimuthal Logging Data Analysis

The OU 7-13/14 project conducted azimuthal gamma-ray logging in selected probes within the 741 Study Area as a means to investigate the spatial distribution of subsurface radionuclides. Four probes were selected for the azimuthal surveys based on existing geophysical logging data. These probes were selected because they contained high levels of ^{237}Np (Table 3-10).